RELATIONS BETWEEN DESIGNER AND PRODUCER.

Paper presented to the Institution, Eastern Counties Section, at Ipswich, by L.H. Pomeroy, M.I.P.E.

THIRTY or forty years ago the chief draughtsman of an engineering works was a sort of Pooh Bah responsible for design, material and methods of construction. Alternatively these functions were assumed by the works manager depending largely upon the relative strengths of the personalities of these gentlemen and the extent to which the capacity of expressing designs on paper was overwhelmed or otherwise by the forcefulness acquired by years of ruthless man handling.

Nowadays, and especially in highly organised departments of the engineering industry, this situation is very changed. The automobile industry for example has become a highly specialised branch of engineering. Its literature is colossal, new developments occur so rapidly that it is impossible for any one man, however capable he may be of absorbing information, to really keep abreast of all the scientific work that is being done in one of the most important industries in the world. Thus, the man or men responsible for the technical direction of an automobile concern have perforce to be concerned with world tendencies in design, to contribute such specialist knowledge as they may possess, and to delegate to competent assistants the infinite number of problems —mathematical, thermodynamic, metallurgical and mechanical— which arise in making the most complex, yet relatively foolproof mechanism ever put into the hands of a non-mechanical public.

Now what are the essential differences between, say, a 100 h.p. triple expansion engine or a locomotive, and, say, a 20 h.p. six-cylinder motor car engine? They are all prime movers, all of them have essentially the same parts, but whereas triple expansion engines and locomotives are made in insignificant numbers, the motor car engine is made in hundreds of thousands. It is therefore highly susceptible to the economic urge of cost reduction by the production engineer, and it is right here where this business of the relations between engineering and production departments begins to come to a head. The viewpoint of the automobile engineer is inherently based upon basic principles of engineering and his success depends upon the extent to which these materialise in the

8th November, 1932.

finished product. The viewpoint of the production engineer is, or should be, the facile and cheap production of the parts designed.

It is not always easy to reconcile the engineer's idea of the design of a part to perform a given job with the production engineer's desire for simple manufacture. There is no one here probably who cannot cite his own examples of this dilemma, of the extent to which the ideals of the engineer can or should be sacrificed to production requirements and the task is not made easier by appeal to experience. Thus, the choice of the number of bearings for an engine crankshaft can call forth the bitterest of disputation. But apart from such major questions of design are a whole host of minor details in which cost variations of hundreds per cent. may be involved because of the lack of familiarity of the engineering department with the possibilities of modern manufacture. It is in this direction that the production engineer can be of the greatest help during the working out of new designs rather than in criticism of the general broad principles upon which such designs are based. The average competent engineering draughtsman with the best will in the world, spending his time year by year in squeezing quarts out of pint pots, cannot in the nature of things be as fully familiar with the resources of the modern machine tool as the men who develop and use them.

In my view every detail of a new design needs overhauling by the production engineer to be sure that the part is made in accordance with the correct balance of the plant available and that no unnecessary or avoidably difficult operations are called for. Good engineering produces the desired result with the use of the cheapest material and workmanship and the least accuracy, and on this matter of accuracy, i.e. the necessity either for absolute interchangeability or absolute precision of an adjustment, a great deal of blood may usefully be spilt.

I will take as an example the cam, push rod and rocker of an overhead valve mechanism. The operation of a camshaft goes to the root of modern overhead valve engine design. For years past the push rod operated valve has been regarded as inherently noisy because of the impossibility of maintaining accurate valve tappet clearances. For this reason, overhead camshafts with their great complications of drive and increased cost have been looked upon as the solution of the problem of making a silent overhead valve mechanism. It is, however, possible by design to make a cam which will give perfectly silent valve operation with 60/1,000ths clearance and allow a greater tolerance arising from engine expansion or maladjustment than the total clearance usually allowed between a valve and tappet. This to my mind is the class of engineering which should be encouraged by production departments.

Now for a few examples in which the interests of the engineering and the production department are at variance, or rather where the extra cost of correct engineering has to be studied and its economics determined.

First a rear axle shaft.

Design (*a*) Fig. 1, is a drawing of an axle shaft made in accordance with the dictates of uniform stress. Design (*b*) is the same shaft made in accordance with the dictates of cheap production. The material and labour cost of Design (*a*) is 33 per cent. higher than

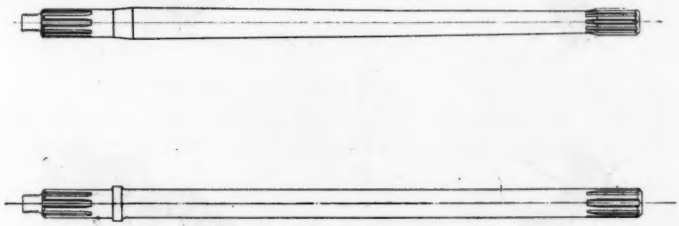

Fig. 1. Design (a) above. Design (b) below.

Design (*b*). Apart from the slight increase in weight of shaft (*b*) over shaft (*a*) what should be in the mind of the engineer in deciding the specification? It is that 90 per cent. of shaft failures arise from fatigue, and that fatigue arises from overstress, and overstress as a rule is a local and not a generalised affair. It is therefore important in all stressed parts to avoid the localisation of stresses.

Whilst it is easily possible to calculate the stress in a circular shaft due to a given torque, and also to devise formulae for shafts of a few known sections not in common use, it is not possible to calculate the stress at the bottom of a keyway or at the roots of a splined shaft.

In this connection pure science comes along with a great aid to the engineer of a somewhat dramatic nature, namely, by the use of soap films. This is done by the apparatus shown in Fig. 2, which is shown arranged for determining the stress in a section of a propeller. A soap film is spread over the section in question, and the circular hole alongside it, this hole having a diameter equal to the area of the section divided by its circumference. The soap films are then dilated by air pressure so that the angle of the film at its boundary is about 30 degrees.

It is then possible by using the auto collimator to determine the inclination of the soap film at any point and the stresses relative to those in a circular section. By using the point *D* attached to the micrometer screw *D* carried in a piece of plate glass the lower point

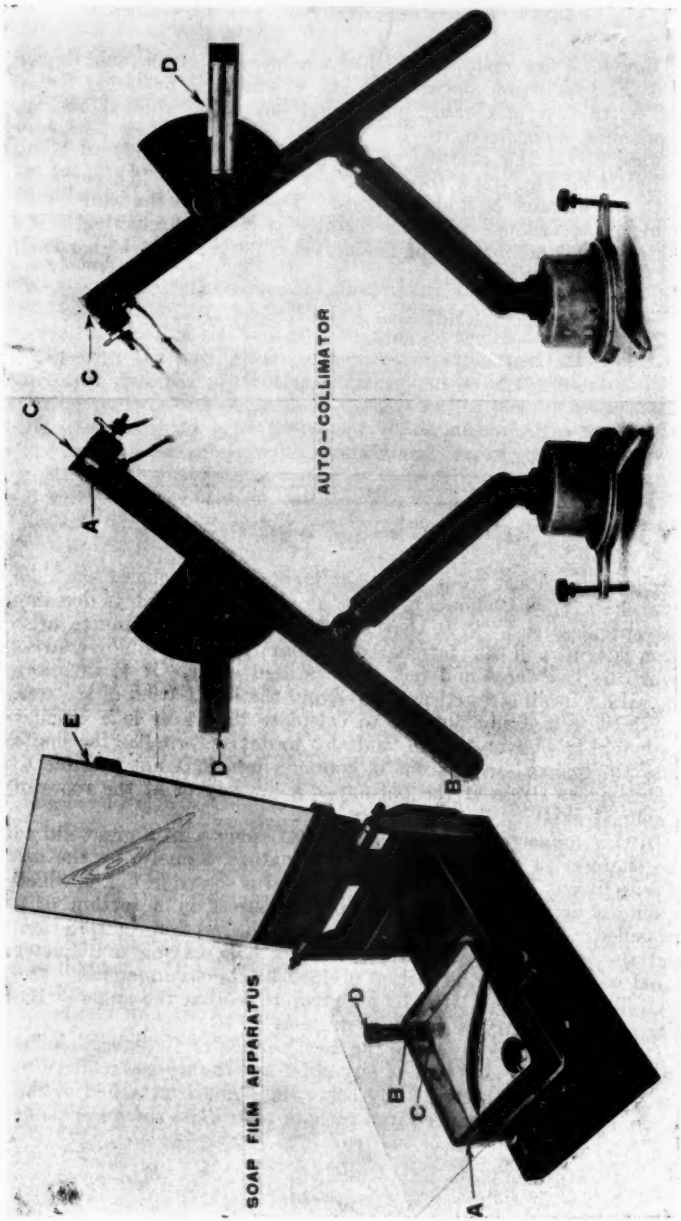

Fig. 2

of the micrometer screw can be made to touch the soap film and the top end to register a point on card *E*, which is suitably hinged so that it can be swung over to make contact. A series of these points plots the contour stress lines of the section. Finally, by measuring the volume of the air under the section by sliding a piece of plate glass over it, and displacing air into the circular film, the volume of which being spherical is easily measured before and after the said displacement, it is possible to determine the strength of the whole section in terms of the circular section, since the strengths are proportional to the volumes under each film.

This method shows up surprisingly well as is indicated by the examples given in the following tables:

TABLE SHOWING THE EFFECT OF ROUNDING THE INTERNAL CORNER ON THE STRENGTH OF A TWISTED "L" SHAPED ANGLE BEAM.

Radius of internal corner.	Ratio: $\frac{\text{Maximum stress.}}{\text{Stress in arm.}}$
Inches.	
0.10	1.890
0.20	1.540
0.30	1.480
0.40	1.445
0.50	1.430
0.60	1.420
0.70	1.415
0.80	1.416
1.00	1.422
1.50	1.500
2.00	1.660

Figs. 3, 4 and 5 show the stress for various radii at the bottom of a keyway and the extent to which a shaft is weakened by the pressure of a keyway.

Tables 1 and 2 and Figs. 2—5 are from "The Mechanical Properties of Fluids," published by Messrs. Blackie & Son Ltd., and reproduced by their kind permission.

With all the above prominent in the designer's mind, perhaps, the production expert will forgive his reluctance to sanction cost saving at the expense of violating well established engineering principles. It is up to him to devise methods to enable us to get

TABLE SHOWING EXPERIMENTAL ERROR IN DETERMINING TORQUES BY MEANS OF SOAP FILMS.

No.	Section :	Maximum inclination	Observed vol. ratio	Calculated torque ratio	Error
		Degree			*Per cent.*
1	Equilateral triangle height, 3-ins. ...	32.06	1.953	1.985	— 1.6
2	Square, side 3-ins.	30.39	1.416	1.432	— 1.1
3	Ellipse, semi-axes 2-ins. × 1-in. ...	30.50	1.143	1.133	+ 0.9
4	Ellipse, 3-ins. × 1-in.	31.01	2.147	2.147	—
5	Ellipse, 4-ins. × 0.8-in.	36.12	3.041	3.020	+ 0.7
6	Rectangle, sides 4-ins. × 2-ins.	31.33	1.456	1.475	— 1.3
7	Rectangle, 8-ins. × 2-ins.	35.28	1.749	1.744	+ 0.3
8*	Infinitely long rectangle	36.00	0.858	0.848	+ 1.2

* On 4-ins. length.

the ideal construction at the cheapest cost. This involves far more than appears at first sight. Nearly every construction, except those in pure tension which are exceedingly few, uses about twice as much material as would be used were it correctly disposed. Thus the

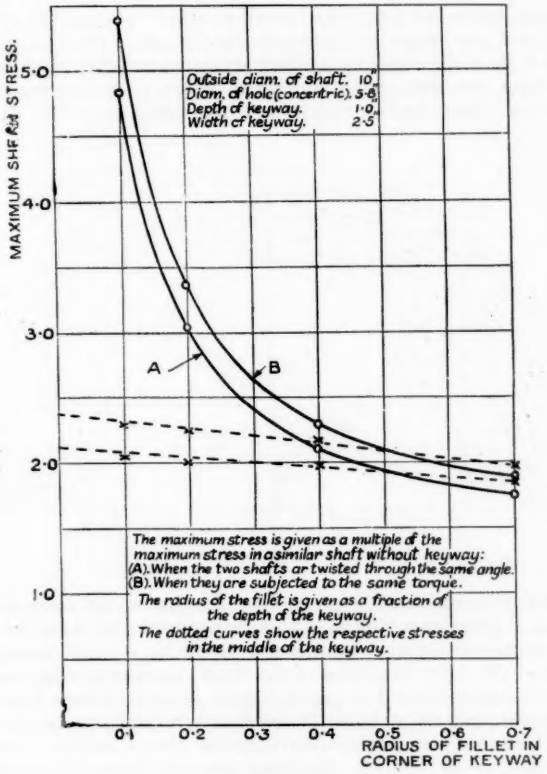
MAXIMUM SHEAR STRESS.
5·0
4·0
3·0
2·0
1·0
Outside diam. of shaft. 10"
Diam. of hole (concentric). 5·6"
Depth of keyway. 1·0"
Width of keyway. 2·5"
A
B
The maximum stress is given as a multiple of the maximum stress in a similar shaft without keyway:
(A). When the two shafts are twisted through the same angle.
(B). When they are subjected to the same torque.
The radius of the fillet is given as a fraction of the depth of the keyway.
The dotted curves show the respective stresses in the middle of the keyway.
0·1
0·2
0·3
0·4
0·5
0·6
0·7
RADIUS OF FILLET IN CORNER OF KEYWAY

Fig. 3

weight and cost of engineering constructions are much higher than they might be if the ideal sections and stress distribution could be obtained by rational and orthodox fabrication. Thus, if one could imagine a crankshaft with hollow webs, pins and journals, at no extra cost, the weight would be reduced in far greater ratio than the

strength, and when the foundry arts become more developed than at present such a crank is an immediate possibility.

The typical British engineer has an instinctive aversion regarding castings, regardless of the fact that all forgings start off in life as castings and the forging process not infrequently masks the defects of the original casting.

I trust these few examples of the relation between the needs of design and production will remove any idea that there is a conflict between these departments. There is no more conflict than between a hobbing machine and a milling machine. Until circumstances demanded otherwise the milling machine could do both. It is the

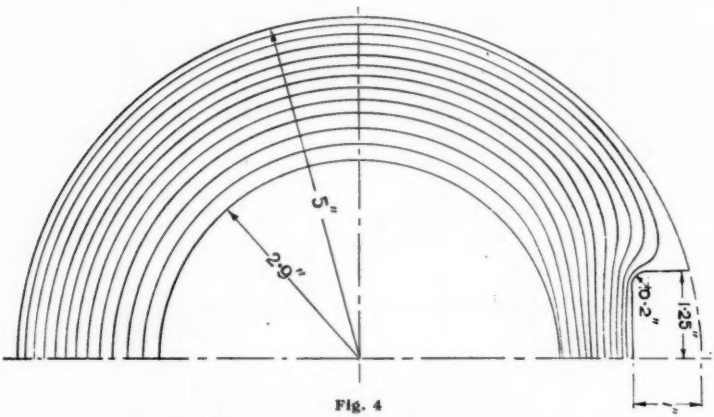

Fig. 4

complexity of modern design and production which calls for subdivision of function which is easy and the linking of these functions which is difficult anyway, and almost impossible without overlapping In a way, the main functions of the chief engineer and his opposite production member is the psychological control of their respective departments and to deal quietly but firmly with the numerous arguments that can so easily arise between the "works" and the engineering department. No small part of these come from the difficulties of interchangeable manufacture, i.e., limits and tolerances.

How often it is found that whilst an experimental engine or car goes through its tests successfully that troubles arise in production. How often do we hear that things which are precisely the same behave differently which, in itself, is a contradiction in terms. What happens usually is that in the experimental stage, tolerances and clearances are altered by expert mechanics to make the job function

satisfactorily, but these are not recorded. Further, there are infinite possibilities in the chance happening of maximum or minimum clearances in experimental jobs which do not consistently repeat themselves in production.

Personally, I do not believe it is possible to make motor cars with all parts interchangeable without sacrifice of endurance or risk of imperfect functioning. In general the variation in working clearance arising through even the finest of limits is very large in comparison with the amount of wear which will cause noise or failure. Thus, consider a 3-inch bore engine in which the cylinder and piston are machined to within .0005-inch, the minimum clearance being, say,

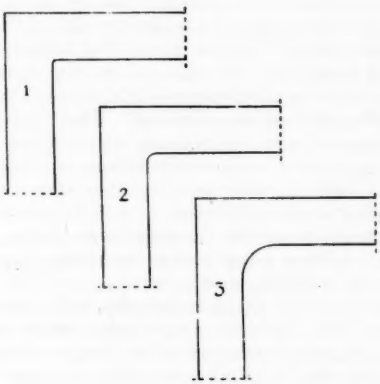

Fig. 5

.0016-inch, and the maximum .0026-inch. The clearance at which a piston will slap is, say, .004-inch, so that the piston which has the minimum clearance will have nearly twice the life of that with the maximum clearance.

In brief, there are many parts in a motor car in which selective assembly is necessary and desirable. This allows for wider machining limits and reduces cost as well as giving a better construction. The actual specification of the desired clearances necessarily falls upon the production engineer for he only is near enough to the product, and in the majority of cases the correct clearance is a matter of bitter experience. Even when a part is made exactly to prescribed limits there are in many automobile components considerations of temperature and distortion which completely upset any predetermined specification of clearances.

Modern engineers think in terms of the thickness of an oil film and

the inherent quality of an engine is roughly inversely proportional to the viscosity of the oil needed for its silent working. All this boils down to what in the old days was called "workmanship," i.e., the quality built into the product by the individual skill of the mechanics who made it. Nowadays in manufacture this skill, and oftentimes intuition, has to be segregated and systematised, and in my view it is necessary for this to be done by the production engineer even if afterwards it is authorized by the engineering department. The doing thereof calls for the highest powers of discrimination and engineering knowledge, and always from the viewpoint that the fewer things which have to be made dead accurately the better. Idealists are the trouble makers in this world.

It is necessary to have ever in mind that an engine, for example, is not a collection of moving parts which are straight and cylindrical. A cylinder when working is no longer so. It is hotter at the top than the bottom and hotter on one side at the top than the other to such an extent as to cause dimensional variations which make the manufacturing limits look insignificant. The crankshaft is not a robust well supported part, but twisting and bending like a delirious snake as it is hammered and vibrated from one end to the other. The crankcase is not a strong iron or aluminium box, but a poor flimsy thing doing its humble best. Add to all this the critical vibrations and loads caused by running reciprocating parts at speeds utterly unknown in other prime movers and then regard the question of clearances with a disillusioned eye.

In presenting a similar paper before this Institution in January, 1929, i.e., before the economic catastrophe which has rocked the world to its foundations, I referred to the danger of over-production. Whilst over-production is doubtless a fallacy from the viewpoint of the economist, there is by now not the faintest doubt that it forms the greatest industrial risk from the point of view of the manufacturer. It arises because things are made which people do not want, not necessarily because they cannot pay for them, but simply that they do not want them. It is, therefore, very necessary to keep industrial undertakings as flexible as possible so that at any time they can change their product with the minimum disturbance, which is, of course, a condition involving the very antithesis of cheap production, because cheap production, as now understood, calls for expensive capital outlay in plant and tools.

The basic principle, however, is, I think, that all doctrines—economical, industrial and otherwise—are inherently weak to the extent to which they are based upon the assumption that human taste and standards of satisfaction are permanent and unchanging. It thus becomes necessary to visualise a product which lasts on the average only as long as the taste for that product lasts. We thus come to the influence of fashion and taste upon the industrial

problem. As is well known, and by some of us at extreme expense, the average woman's idea of permanency in dress is from four to six months. At the other end of the scale the average person's idea of permanency in, say, houses, is from 15 to 20 years, yet these same houses are habitable in succeeding stages of decay for anything up to a hundred years.

As soon as we begin to regard the products of industry as having a definite life in accordance with the dictates of fashion, which is largely based upon scientific and artistic progress, we should then have our products made so that they automatically wear out or fall to pieces, or otherwise scrap themselves and are replaced by others of up-to-date design.

Unfortunately, the whole doctrine of the economist, particularly in this country, is that permanence is economically justified and waste is economically unjustified. I differ from this entirely, for I regard waste or destruction as the only way in which the ground can be prepared for that which is new, which in turn makes what is usually known as " work," which, again in turn, offers 99 per cent of the community the only chance they ever have of improving the conditions in which they find themselves.

The bearing of this doctrine is very far reaching, not only in the design of the product, but also in the manufacture thereof. We find in many large works, machine tools fifteen to twenty years old still doing good work, but obviously not doing anything like what could be done with the same expenditure on machine tools of up-to-date design as the old tools originally cost. It is, therefore, necessary for an industrial product to bear such a rate of profit as will allow the relatively speedy depreciation to zero value of the plant and buildings used for its manufacture. One has only to regard the plight in which the Railway Companies now find themselves to appreciate how enormously they are handicapped by building rolling stock at high costs to last for thirty years when by proper study and cheapening of material and design it could earn its keep and be thrown away in ten years.

These may all seem matters rather foreign to the relation between the designer and the production engineer. They are, however, very basic matters upon which a good deal of thought is now being brought to bear, and which may have a very vast potential influence in the not very remote future, for after all, whilst the majority of people want leisure they all want employment, and employment is necessary not only to keep people alive, but to apply the discipline and the opportunities for progress, which are the basic needs and instincts of mankind. Somewhat paradoxically I have no doubt that with these means which will increase employment as such, the next major world political movement will be that of the shortening of hours, which will increase leisure and also the intensity of employ-

ment. My only excuse for introducing these matters into this lecture is that those who are philosophically inclined may possibly be stimulated to direct their minds to the fundamentals of their profession.

I have tried to present to you what may be termed the engineering state of mind as regards the problems of the production engineer. There is no question of conflict, but only of relation. The engineer must have the last word, but it is for the production engineer to put it in his mouth.

Discussion.

MR. C. H. WOODS : I wish to thank Mr. Pomeroy for his interesting lecture. As a result of the lecture one can see how necessary it is for the production engineer and the designer to understand each other's point of view. Also Mr. Pomeroy has brought home how necessary it is for the designer to realize what the production engineer has to do. There is one question I would like to ask with regard to flexibility. Is there any real road to meeting either increasing or decreasing requirements ?

MR. POMEROY : In reply to Mr. Woods, the essence of works' flexibility lies, of course, in the product itself. It is now being brought home to the American motor car trade that the installation of highly specialized machinery and equipment can only be justified by outputs and sales large enough to wipe out the initial expenditure during the life of the model, say, two years. Experience is now showing that the huge sales upon which highly specialized plant and equipment were predicated do not necessarily materialize, so that it is much better to have plant applicable to a range of models, present and future, i.e., flexibility rather than fixity.

MR. BRAZIER : I am very interested in alloy metals and the fatigue of same, because we generally have a lot of trouble with some metals with regard to fatigue, and it is generally the case when you discuss this with the designer something must have gone wrong with the heat treatment to the materials in question. Can the lecturer inform us as to what are the best steels for parts that are subject to high stresses, and have to withstand fatigue over a longer period than the ordinary carbon steels, and also what is his opinion with regard to alloy steels as compared with carbon steels correctly treated ? With regard to the round shaft which the lecturer put on the screen showing us the stress on the keyway and the radius on the bottom of the keyway. The stresses on this part of the shaft appear to be very high. Is it possible for the high stress in that narrow part to distort the shaft in time ? I was also interested in the illustration the lecturer gave when he said, with regard to the life of old machines, that it would be wise for manufacturers only to work them for a reasonable number of years, and put as much money away as they possibly could out of profits and then buy new machines in due course. As no general engineering concerns are making any profits to-day, would the lecturer kindly inform us how he arranges to buy new machinery in these strenuous times ?

MR. POMEROY : Mr. Brazier raises the matter of special alloy steels versus carbon steels. This matter is one which deserves much attention from both the designing and production viewpoint. In

the case of a rear axle shaft, for example, the highest class of material is justified because the increase in dimensions to enable material of a lower tensile strength to be used, involves an increase in the size of ball bearings, hubs, etc., which outweighs any saving made by the difference in cost between the alternative materials for the axle shaft. There is no doubt, however, that as a rule alloy steel is over-rated and carbon steel under-rated in regard to its fatigue resisting properties, largely because with alloy steel correct heat treatment is absolutely necessary, whereas with carbon steel it is not apt to receive sufficient attention. With regard to the stress at the bottom of the keyway in the shaft, of which stress diagrams are showm, it must be remembered that these stress diagrams are those which are found when the key is not in its keyway. In actual practice the presence of a tight-fitting key materially relieves the stress situation at the bottom of the keyway. The diagrams do, however, indicate the value of a radius at the bottom of a spline, which may be a sliding spline, and, therefore, allows the bottom of the keyway to be subjected to the high stress indicated. It is not so much a matter of distortion of the shaft as the fact that fatigue cracks may be initiated. The present day situation of general engineering concerns in respect of the purchase of new plant is, of course, a very serious one. Fortunately, however, business is not all a matter of cost of production and novelties can be sold at prices which allow of the use of even old-fashioned machinery. However, where a firm is faced with a non-profitable business, and no ideas for a new class of output which can make it profitable, the combined effects, together with obsolete plant, make the outlook somewhat hopeless.

MR. GALBRAITH : I join in thanking Mr. Pomeroy for his very lucid and excellent lecture. I am sure that all present have profited by it. Mr. Pomeroy has proved beyond a shadow of doubt that the production engineer holds a very responsible position in the modern works of to-day. I would like to ask Mr. Pomeroy what he thinks of limits and tolerances generally ? On these points the production engineer often has long arguments with the chief or designing engineer concerning what is suitable for certain work.

MR. POMEROY : In reply to Mr. Galbraith, there is no doubt a very great tendency on the part of both the production engineers and designing engineers to call for limits which are far too close, perhaps, on the same basis that if everybody kept the Ten Commandments nobody would go far wrong. On the other hand, experience shows those who show a discreet capacity for violating the rules of the game as laid down for the proletariat often profit enormously thereby. Thus, in engineering there are certain limits which cannot be too closely observed, and others in which large tolerances are not only permissible but often desirable. It is the nice sense of discrimination

in these which makes for the difference between economical and commercially successful products, and those which are not.

MR. L. WIDDAS : With regard to the diagrams of the stresses on the hollow keywayed shaft, I noted that the stress lines were closer together on the inside of the shaft just below the keyway. Was this an error in the diagram or an actual recorded fact ? Also, what would be the stress distribution in the neighbourhood of the keyway in the case of a solid shaft as compared with the hollow one shown ?

MR. POMEROY : In reply to Mr. Widdas, the stress inside the keyway is approximately a minimum when the radius at the bottom of the keyway is .7 of the depth of the keyway. The stress between the keyway and the hole in the shaft is approximately 1.6 times the mean stress. Thus, the strength resisting capacity of the shaft with no keyway is represented by the number 805, whereas the strength of a shaft of a radius equal to that at the bottom of the keyway is represented by the number 488. With regard to the relative stress distribution at the bottom of the keyway as between a solid and a hollow shaft, it is difficult to imagine that there would be much difference in this unless the hole through the shaft were much larger than in the case in question.

MR. HANCOCK (Member of Council) : I wish to emphasize the importance of engineering and design being the dominant note in any automobile concern, and the importance of the production engineer extending every possible facility to the engineering department in having as much freedom as possible, so as to perfect the design. With this in view, I would again point out the importance of flexibility of plant, so that the works can, in a reasonable time, introduce new and improved designs into the product. Flexibility of plant is a point that I have raised before on many occasions. I would like also to direct production engineers' attention to the importance of disposition of functions and plant. Savings can be made by the mere reallocation of plant with a very slight outlay as compared with savings possible by the purchase of new machinery. This is a matter that all production engineers should give their attention to. I agree with Mr. Pomeroy in regard to the question of selective fits, particularly for such items as pistons to cylinders. In this connection I may mention a system of selective fits which I have seen in the United States. This was a system based on four colours, namely, that by gauging a piston on a dial gauge to four colours, and by gauging a cylinder bore on a dial gauge to four colours, four grades of sizes were arrived at, so that by assembling a red piston into a red cylinder bore, the correct clearance was maintained, although over the range of four sizes, there was a very wide limit. On the question of limits there is now sufficient data available for use by the engineering department for fixing limits, and it is the engineering department's responsibility to specify limits,

but, naturally, based upon practical experience. The only point for discussion is whether the engineering departments use to a sufficient extent the practical experience which is available.

MR. POMEROY : Mr. Hancock's remarks call for very little comment in view of the way in which they support the views expressed in the paper. The question as to who should decide limits is, of course a vexed one. The engineering department, as a rule, suffers from lack of intimate connection with the realities of production, whilst the production departments suffer because of their lack of knowledge of the fundamentals of design : thus the practical experience so often available is based on mere theory. The best method seems to be that of giving ample opportunity for those responsible for production and design to clash their heads together on the general theory that " truth comes out of strife."

A cordial vote of thanks to Mr. Pomeroy concluded the proceedings.

DESIGN AND MANUFACTURE OF WELDED STEEL FABRICATIONS.

Paper presented to the Institution, Coventry Section, by H. W. Hawkins.

Review.

OF the many welding processes developed or perfected during recent years for industrial purposes—none has made such rapid advance and found unlimited application as the metallic arc process of fusion welding, and to-day we find it not only extensively used by those trades whose products have always been built up from mild steel plate and sections, but also and in no less degree, employed by manufacturers for the replacement of iron and steel castings by a welded mild steel construction both large and small. This latter development has made remarkable strides and providing the principles of design necessary for efficient welding be applied, there would appear to be but very few industries that will not make use of fusion welding in one form or another. The extent to which fusion arc welding has entered into industry will be appreciated from the following trades, which by no means exhausts the list :

For the replacement of riveted structures we have : Bridgebuilding, shipbuilding, tankmaking, cranes, railway and tramway trunk and undercarriages, boiler making and pressure vessels, building construction, piping and general riveted constructions.

For the replacement of iron and steel castings, we have : Electrical apparatus in general, including stators, rotors, bedplates, pressure and vacuum tanks, also transformer casings, machine constructions, engine crankcases and components, machine tool beds, etc., mill and heavy machine housings, frames, etc., etc., including builders ironmongery in general.

The extension of fusion welding in the sheetmetal industry is well known and has now extended to motor car and aircraft constructions and the processes are now efficiently applied to non-ferrous metals, nickel alloys and stainless steels. Indeed the applications are so extensive that any one industry affords material more than sufficient for any one paper, and therefore, as time is limited, we will centre our attention upon the application to the heavy industries and particularly the products of electrical undertakings. The fundamental principles, however, apply equally to each and every application, any differences as between industries being that of accommodation.

This intensive application of the process has obviously been brought about by the many advantages it affords such as: (1) *Guaranteed strength*; (2) *saving of materials*; (3) *economy of manufacture*; (4) *reduction of machining allowances*; (5) *elimination of pattern making*; (6) *no risk of loss due to faulty castings*; (7) *no risk of machining losses on faulty castings*; and of major importance to many undertakings the elimination of noise as compared with riveting.

It is not to be inferred from this formidable list of advantages that fabricated constructions are free of trouble. On the contrary, many are experienced if due care is not taken in both design and manufacture; however, experience is the best teacher and whilst it is not possible to detail the many pitfalls that beset an individual job, various points to guard against will be indicated during the review of the manufacturing and design requirements. If handled with discretion, this universal joiner of material has no equal, It not only provides an efficient joining medium, with the minimum of preparation, but also enables a construction to be developed along the most economic lines, by giving perfect freedom in the selection of materials, not possible by any other means.

As regards the advantages, many of which need no explanation at this stage of the paper, these will be referred to later on. We will consider the first three in detail and endeavour to obtain a true appreciation of their meaning.

Guaranteed Strength.

Since we are using mild steel as the foundation of our constructions, it will be accepted as providing all that can be desired for most purposes when compared with cast iron and cast steel, and it remains, therefore, for us to have the same confidence—firstly in our design and secondly in the welding.

The former is a matter for the engineer and although inconsistencies sometimes enter into a design that may give trouble during manufacture, it is a point that can readily be accommodated to give the guarantee required. The welding however, may be a source of concern, but providing one employs good materials and equipment in skilled hands there is little to fear from this source. Fusion arc welding has so developed that a good weld is little, if anything, less in physical properties to the base metal, and as it is usual to write down the loading of welds to a safe figure, say at 75 per cent. of the base metal, it will be seen that to give a guarantee of strength for a fabricated construction is of little concern in these enlightened days.

A graph of the result of routine tests on some 40 welders, carried out under ordinary working conditions, plotted from the tensile test results for each of the welders shows an average reading of 27 tons per square inch with a maximum of over 30 tons per square inch and

a minimum of 24 tons per square inch. Results such as these are sufficient indication that properly conducted welding is a highly efficient means of joining materials together. Even the lowest result gives the design factor a safety margin of $33\frac{1}{3}$ per cent., which, together with the usual safety factor associated with the design, should remove all doubt as regards the strength of welding.

Factors such as ductility and fatigue resisting properties, whilst necessarily playing a highly important part in certain classes of constructions, need not be seriously considered in respect of many of the examples, and for this reason we will for the present presume the previous illustration of tensile properties, equal to our requirements. The object of this division of the properties of welds is because it is possible to apply the different processes we shall primarily consider, into two main classes. It will be appreciated that the welding required for say—by way of example—a baseplate, need not be of the same character as that required and essential for a pressure vessel. Each application is very well served by a totally different technique and as these have now reached a high state of efficiency, we are able (and in fact it is very desirable) to consider and define the process to be applied to a particular construction if efficient and economic results are to govern our efforts. The divisions are :

(1) *Welding technique as applied to pressure holding and highly stressed constructions* ;

(2) *Welding technique as applied to a static or lightly stressed construction.*

For the former class of apparatus we are governed by the safety factor as distinct from the economic factor, which is the ruling condition and may be safely employed for the latter class of apparatus. So long as there is no confusion of thought as regards the process to be applied, we have two highly efficient tools for use on the respective applications and as the latter has an ever extending field of application, the technique of its process, whilst not being of the same order as that required for the former class of apparatus, will, nevertheless continue to give results well up to the service required of the application.

By careful selection of the subject considerable economies can be effected, these being contributed to in no small measure by the time factor, which by enabling manufacture to commence immediately, is a great asset to industry in these days of shortened deliveries. Before considering the various welding processes in common use, we will conclude this review by referring to the scientific side of the subject, without which industry would not be able to register the marked advances of the past decade.

Research in fusion arc welding by the chemist and metallurgist has placed the process in its correct source of development, in that

progress has only been possible by a minute study of the subject and particularly of the phenomena within the arc, to the end that corrective measures have been determined to the exclusion of undesirable elements that may be absorbed by or arise from the application of an incorrect technique or by the use of unsuitable materials. The field of investigation in the laboratories and workshops of many scientists both abroad and at home, has covered every phase of the subject, and whilst the evidence at hand may not be considered conclusive, in the light of current progress, it has nevertheless, been the mainstay, upon which the process has reached its present status. The quality of present day arc welding as compared with the results of early efforts, is sufficient evidence of the necessity for these laboratory investigations, and their continuance will lay the foundation upon which the future progress of the process will be built.

These researches will suffice to indicate the character of the work carried out by laboratories, to give the welding industry the necessary data for its development and, I would add, confidence, to those who hesitate to make use of the process. For the operative side of the process the electrical engineer has provided us with efficient welding sets, capable of maintaining a stable yet flexible arc with a quick recovery value to accommodate the variations of manipulative welding.

Without these characteristics, good welding is not a practical proposition and indeed a welder's job would be very difficult, were it not for reliability of the modern welding set.

Welding Processes.

We will now consider the various welding processes in common use, briefly reviewing the speciality processes, concentrating upon fusion welding by means of the metallic arc. The principal processes are classified under two main headings as characterised by the condition of the surface during the process, i.e., Plastic and Fluid (or Fusion).

The plastic group embraces the system of electric resistance welding under three headings. Spot, Seam, and Butt. Each of these applications is mechanised and under automatic control. The butt welding system provides an economic means of efficiently welding sectional materials together, for such products as frames, curbs, rings, shells, etc., and as a general purpose tool is of great value to a welding shop for a variety of purposes, with the standard set up and by the provision of suitable contacts a big variety of work can be handled.

The fluid or fusion system has two main branches and except for the means of heating they are practically analogous, in that the preparation for the application of either system is conducted along

very similar lines, irrespective of whether they are applied by hand or automatically.

The application by gas torch is much the older system and is still much in evidence at present especially for thin materials. It also finds favour in certain industries for welding on heavy section materials, probably because of the normalising effect of the excessively heated area occasioned by the use of a flame, but few modern fabrications lend themselves to gas welding as with the heavy welds required, considerable heating would take place, resulting in excessive distortion of the structure, difficult to correct, apart from the enhanced cost of welding as compared with that by the electric arc. Gas welding, however, will always have its economic applications, and not infrequently it finds useful application in association with the electric arc.

The electric arc process, as its name implies, is accomplished by means of striking an arc between an electrode and the work to be welded. The carbon arc system using a carbon pencil for the electrode, although first in the field, has limited application at the present time, being replaced by the metallic arc process.

The metallic arc system is conducted similarly to the former except that the electrode in this case is a metal rod connected to one pole of the circuit with the work connected to the other pole. The electrode is similar in elements to the base materials, and designed to unite therewith to give a joint of equivalent physical properties to the base materials. This ideal is very difficult to obtain, the point being appreciated when it is realised that we are attempting to assimilate wrought and cast material into a composite whole.

The operation is aggravated by the slow progression of the process, and unless the control is in experienced hands the resultant weld falls far short of the ideal. The process consists essentially of striking an arc between the electrode and the work, maintaining it at a constant value as regards arc length, and depositing the fused metal from the electrode at a progressively even rate. These simple operations must be efficiently carried out to ensure sound welds, the manual contribution calling for a training no less thorough than the attention given to the scientific side of the process.

Since the majority of welding operations have of necessity to be carried out by hand, manual dexterity bears a very definite relation to efficient welding and although the other factors are now designed to make the operation easier, the manipulation of arc welding in its truest sense is no less exacting than that expected of operators in skilled trades. For this reason it is necessary to have a standard of training which will be referred to later.

Although fusion arc welding has been in use for many years,

firstly by the carbon arc, and later by the metallic arc, its industrial development really originated during the Great War. The discovery of the practical possibilities of the metallic arc process of fusion welding is understood to have arisen from the fortuitous fact that in the process of wire drawing sufficient lubricant remains on the wire to furnish the flux needed for a weld. This residual coating to the wire must not be confused with the coating given to electrodes as now made, but it is to be presumed that this chance happening initiated the development of present day coatings.

There are three types of electrodes in common use, each possessing a manipulative technique and character peculiar to itself.

The primary use for bare wire electrodes is for the welding of constructions not subject to shock and alternating stresses, because the weld resulting therefrom, whilst possessing good tensile properties as previously illustrated, is comparatively low in ductility and fatigue value. Bare wire welding however has made immense strides during the past two or three years, and it is believed to be only a matter of time before the laboratory will give us a wire composed of elements designed to expunge the mal effects of atmospheric contamination, and without the objectionable residues of electrode coverings.

The coated, i.e., paste covered, electrode is designed to facilitate welding. The resultant weld is little if any superior in physical characteristics to that obtained by good bare wire welding, although the fused coating affords some measure of protection of the arc from atmospheric contamination. The difference in cost as compared with bare wire is considerable and may be justified by the somewhat better finish they give to a weld for certain classes of work, but an experienced bare wire welder can usually give a weld finish equal to the most exacting requirements of welded work.

The covered, i.e. heavily coated, electrode is in a class by itself and is designed to afford complete protection from atmospheric contamination during welding by forming a gaseous shield around the arc and some coverings protect the weld by forming a dense slag on top of the weld, allowing same to cool slowly, offering a minor annealy value to the welded joint.

Coverings are also implied to act as a fluxing agent for the material and as a reducing agent for occluded gases such as oxides and nitrides. The gas generated by the fusing of the covering facilitates the maintenance of a steady and constant arc stream. For this reason covered wire welding is comparatively easy as compared with bare wire welding and in consequence through this cause alone much covered wire welding is carried out where bare wire would give all that is necessary. With covered wire welding, however, we have a vehicle for the making of welds with physical characteristics more nearly approaching those of the parent metal,

and in fact certain processes are now prepared to guarantee welds equal to the materials they join, and whilst this may be true physically, there are minor chemical differences, and in fact it is suggested that whilst the physical characteristics are required to be alike, the two elements may be entirely different chemically. This thought is significant when one considers a brazed joint.

The shielded arc process of welding is effected by the maintenance of an atmosphere of hydrogen or other reducing medium around the arc and employs bare wire for the electrode. The operation is usually semi automatic in character. This system gives high quality ductile welds, but has the same objections as gas welding for general constructions.

A further process that can be depended upon to give quality welds is known as the atomic hydrogen process which is a combination of the electric arc and gas welding processes. In this system an arc is the initial source of heat but the actual fusion of the parts to be welded is brought about by a so-called flame as in the gas process. The method is effected by passing a jet of hydrogen through an alternating arc formed between two or three tungsten electrodes. The high temperature of the arc breaks down the hydrogen molecules into atoms, which on passing through the arc, re-combine into molecules and in so doing give up the heat absorbed during dissociation. The resultant flame of hydrogen has a temperature of about 4,000° C., and which not only completes fusion but also affords full protection of the weld from atmospheric contamination.

This method of welding gives strong ductile welds with a very smooth finish and is most suited to the welding of thinner materials. It is not yet a serious competitor for arc welding except for particular applications in mild steel but it is very useful for the welding of alloys such as high chromium and nickel steels, etc. A filler rod similar to the metal to be welded is generally used, its character being adjusted to compensate for losses during welding.

The atomic hydrogen method is adapted to either single or three-phase supplies, two electrodes for the former and three electrodes for the latter. Like the gas method it cannot be economically applied to general fabrications.

Automatic Welding.

Each of the methods discussed can be applied to automatic purposes. The gas and atomic methods being served by providing a feeding mechanism for the torch or work and if required gear for feeding the filler rod to the torch as welding progresses. In automatic arc welding however, the conditions are more exacting, because it is necessary to have a special welding head which feeds the electrode as welding progresses at a rate under control of the

arc voltage and so accommodates variations in the preparation of the joint to be welded within fairly broad limits. Too much variation is not conducive of good welding because a long arc is prone to cause burnt material and therefore it is desirable to have accurate preparation so that a constant arc is maintained throughout the run of weld. If this is not looked to—automatic welding has little if any advantages over and above hand welding.

Automatic welders are obtainable in various forms but it will suffice to illustrate two types and some of their applications. Firstly we have the seam welder, with a combined automatic head and travel carriage. Secondly we have the plain automatic head that can be applied to any type of racking and revolving mechanism for the work. Bare or a lightly fluxed wire is usually employed, but there are now specialised systems that make use of covered electrodes.

Welding Speeds.

The advantages of automatic welding lie chiefly in the elimination of the human factor, but to ensure this the preparation of joints and set up is much more exacting than for manual welding and, secondly, the speed of welding can be considerably increased. It is not suited for general work but will show up to great advantage on mass production lines for which quick loading and locating equipment should be provided.

Welding.

Since every substance has a definite melting point it is apparent that the soundness of a weld depends upon the method of effecting and controlling liquifaction of the metal wire or electrode, base metal and deposited metal.

There are many factors effecting fusion, such as : Physical and Chemical properties of base metal and electrodes—Fluxes, whether applied independently or in the form of electrode coverings—Current and electrode size—Arc length—Polarity—Characteristics of Welding Set—Temperature—Conductivity of materials—Preparation and Cleanliness of joint also operation—etc.

The welder has to exercise control over certain of these factors, viz :—Choice of electrode, size and current adjustment to suit, also deslagging when necessary. It is also essential that he maintains a short and steady arc, so as to have constancy of fusion. A long arc will cause burnt metal and porous welds. He must also see that the weld is continuous at stop and start of each electrode used, and generally ensure that the weld is uniform throughout its length at each stage of welding. For his guidance it is usual to provide a chart of welded joints, giving the number or runs of weld metal per given type and size of joint, the size of electrodes to be used for

each run, and the average current value, also welding times per foot of weld.

The rate of deposition per size of electrode, usually from 12 gauge to 4 gauge, may vary within fairly wide limits, without seriously affecting the deposited metal. A low current value however, slows down speed of welding and will probably cause bad fusion, whereas high current value, unless the speed of welding is increased in proportion may cause excessive penetration and undercutting of the welded joint.

The current values for covered electrodes are slightly lower than for bare wire as shown on the chart of butt welds. To compensate for abnormal conditions the current values may have to be extended above and below the average, but such action should only be taken as an expedient.

The current values for automatic welding per electrode size are appreciably higher than those quoted for hand welding and are possible only by virtue of the mechanised control.

The lower values are for thin materials and the higher values for thick materials. In this respect great care has to be exercised when welding thin to thick material, because of the need for using a high current value to ensure adequate fusion with the thicker material, it being necessary to concentrate the arc upon the thicker member with its edge barely engaging the thin part. Current adjustment is also often influenced by the disposition of the joint and the direction of welding. The training of a welder to discern the current value and other requirements of any fabrication is a matter of long practical application, not possible during training proper.

Developments have made possible the extension of arc welding to thinner materials than now commonly joined by the electric arc, so encroaching upon the range of work generally gas welded. The introduction of 16 and 14 gauge electrodes has made this possible. At the other end of the range, larger electrodes are being applied using much higher current values, designed to complete a weld at one run instead of the multiple runs now necessary. There is little information upon this development, and whilst it may ultimately be a practical possibility, it is so contrary to present fusion welding technique, that its successful application will be but another anticipation of the art.

Direct current is mainly employed for most welding purposes, the supply being taken from a motor generator set either for single or multi-operation. For bare wire welding the electrode is connected to the negative pole of the generator and the work to the positive pole, but the reverse is usually adopted for covered wire welding although it is not necessarily essential, however, best welding results are obtained by this means when using covered electrodes and especially so on thin materials, but for heavier

sections it is probably an advantage to change the polarity making the covered electrode negative because of the greater heat generated at the positive pole so giving a more equal distribution of heat as between the mass of work and electrode. This applies to low carbon steels only, but if the base material is of high carbon quality or an alloy, the electrode is usually connected positive for good welds.

Alternating current is employed to some extent for thin materials and erection work, the supply being taken from suitable transformer equipment, which is comparatively light as compared with the motor generator set for D. C. welding, and in consequence has the advantage of easy portability. A. C. is at present only suitable for covered wire welding.

Training.

Now that welding has entered industry in no uncertain manner, being backed by scientific research, it is evident that its development will be hastened, by not only training welding operatives, but also all forces connected with the fabrication industry.

Welding is becoming more and more specialised, and in consequence it is desirable and necessary to educate and train all who are connected with the industry if best results are to be obtained, and in suggesting a field of action, training can well be provided, for engineers and draughtsmen on the technical side and for supervisors, inspectors and instructors on the practical side, in addition to the training established for practical welders and machine operators. This latter is practically all that is being done at present, and whilst much progress has already been made on the engineering side of the industry, these additional educational services are essential for the future establishment and extension of the application of welded fabrications.

For the training of practical welders it is desirable to set apart from the actual welding shop a school or training quarters so that the trainee or student may concentrate upon the acquirement of welding technique through its various stages, so that at the end of his training period he is able to lay a good weld in all three planes, i.e., horizontal, vertical, and overhead. In addition to this he is taught how to use the apparatus and generally fitted in elementary technics connected with the art. Following training and during his employment upon the production of welded constructions, he is periodically tested and if necessary is returned to the school for further training.

Design.

The class of design, which we are about to consider, will be understood to relate to constructions, built up of low carbon steel plates and sections, including forgings as applied to the products

of mechanical engineering as distinct from structures of a civil character. By this is meant constructions in steel for the replacement of castings particularly in cast iron, as distinct from structures in steel such as bridges, buildings, etc. For the latter it may be said the only change in design is that required to meet the requirements of rivetting by welding, and although the two methods call for a definition peculiar to themselves, the change is not so pronounced as in the class to be reviewed.

Towards the beginning of the paper we considered some of the advantages offered by the substitution of weldings for castings, and whilst these are substantial, it is contingent upon a good design suited to and lending itself to efficient welding. This is fundamental, but it does not follow that a copy of the cast form is a good arrangement. In point of fact the further one gets away from a cast outline the more efficient will a welding be, and not infrequently it is very desirable to reconsider the design of the whole product so that those components to be made in steel are at least afforded a form or outline capable of being efficiently manufactured.

There is no precedent for the design of weldings, and in consequence the finished article may not have the customary pleasing lines of a casting. However, there is but scant relation between outline and servicibility, and as a welded design is best arranged to accommodate standard materials and the application of the process we are considering, it follows that a designer is called upon to initiate an outline subject in the main, to these considerations. An elementary illustration of this condition is that of a baseplate, and again of a stator frame, and in like manner other efficient constructions will be found to follow suit.

With the advance of welding, design has kept apace—the one furthering the other. The technique of design for welded constructions is becoming stabilised, and with each new application inherent difficulties diminish, excepting perhaps with reference to residual and contractual stresses, but as these are ever present, by virtue of the working and welding of the materials, and even in the raw material itself, it is not always possible to anticipate some neutralising action to make the construction stable, unless by heat treatment in detail and/or as a whole. Normalising is not often carried out other than for specialised constructions, excepting perhaps on certain details to relieve stresses set up by cold working, etc. Much may be accomplished, however, by the designer, in arranging welds to neutralise the effects of residual stresses, in a similar manner to that taken by the welder, in arranging the sequence of welding to avoid undue distortion of the welded assembly. Little, if any, consideration whatever is paid to this aspect of design, and although the omission does not seriously affect the

average weld, it is not unknown for welds to develop a crack or cause undue distortion of the construction. The magnitude of the stress may be gauged from the contraction of a weld from its freezing to atmospheric temperature being in the region of .012 of an inch per inch in each direction, this being the converse of the expansion of mild steel when heated to about 1,800° F.

It can be shown that the stress set up by virtue of the contraction may readily exceed the elastic limit of the weld for the material welded, and if such is the case, the only safeguard of the latter lies in its flexibility and consequent distortion. It therefore appears necessary for the designer to give due consideration to the probable effects of undue stressing of the structure, and whilst it may not be possible of accurate solution, the arrangement of welds is a function of design in no less degree than the strength of the construction itself.

Designing in steel gives a freedom of sections not possible in cast iron or cast steel constructions, in that the sections which may be used is limited only by the requirements of the design and not by the process of manufacture. As regards weight, this feature has a twofold advantage, firstly because of the reductions possible by reason of the difference in strength, and secondly by reason of the reduced sections that can be employed for many of the details entering into the makeup of the construction.

The reduction in machining allowances will also be apparent, and a further advantage of welded construction lies in the possibility of manufacturing to the elimination of machining operations entirely, examples of which will be shown later. This system has its limitations, but it affords considerable economies on large constructions. Design in general should aim at supplying a welding in place of a casting for machining following completion, because the manual work involved in manufacturing a welded construction may readily occasion costs far in excess of machining operations. As an aid to the designer the institution of standard joints has rendered valuable assistance, and these, together with a simple nomenclature for drawing reference, have made the descriptive treatment of welds a very simple operation.

There is as yet no standard joint chart for this country, but a method of imparting the requisite information for the usual types of welded joints has been devised. There are many modifications to these standard joint forms, but as they are brought about by constructional features only, their symbolisation for instructional purposes on drawings is not conducive to easy interpretation in the shops, and also may cause confusion where a large number of draughtsmen are employed. For the same reason it is necessary to have load charts or tables for use in the Drawing Office.

Under normal conditions of design, it is usually assumed that a

weld should be equal in size to the thickness of the base material, and whilst this may be true for butt welds it does not follow that the same reasoning should hold when applying fillet welds, because of the frequent combination of materials of unequal thickness, and in such cases, leaving other considerations aside, the chart affords a ready means of fixing the most efficient size of weld to employ. Such charts are universal in their application, accommodating the weld from any quality of electrode or process in mild steel.

The equalisation of load in all other forms of joining materials together, is brought about by the flexibility of the connection, but in welding, the very rigidity of the joint makes this equal loading impossible, and as some measure of flexibility in a construction is generally desirable, a design in steel should be allowed to have some measure of breathing, so as to absorb temperature changes and minimise the usual effects of residual stresses.

It is most important, therefore, that the designer bears in mind the foregoing considerations, because it is recognised that no product is more subject to variation in strength or more completely in the hands of the mechanic than that which is fusion welded. The integrity of the welder is essential for the successful application of the process, and in consequence of this factor it is equally necessary for design to anticipate conditions that tend to eliminate the unknowns arising in a construction when welded.

This is very true of all constructions, and particularly so in connection with those that depend entirely on the welding for their security. By this is meant the practice of piecing together the various details in continuity. There is, however, another form of construction not often made use of that would tend to reduce the amount of welding and hence disturbances. I refer to a method of interlocking details so that loading is directly on to the material, employing the welding merely as a means of restraint for securing the parts in their respective relation. Such interlocking as mortice and tenor, scarved and dovetail joints may be readily accomplished by means of flame cutting equipment, the practice being suggested for application on the more important structures besides offering other design facilities.

As a final observation upon the question of design, it is fitting to record that much good work is being done by the Drawing Office, but withal, with perhaps the exception of the simplest construction, there is much that can yet be done by the designer by giving due consideration to features as set forth above, and whilst it is not presumed possible to ensure complete immunity from these inherent obstacles to normality, it is at least possible to reduce their magnitude by keeping the amount of welding in a construction down to a minimum and attempt to balance the residual stresses that may arise therefrom.

Manufacture.

The manufacture of steel fabricated constructions by the engineering workshop has introduced many processes that were previously the domain of the structural and boiler yard. The incorporation of these activities to a highly technical environment has brought about many changes in the manipulation of the same materials by virtue of the necessity for handling same, probably with equipment not originally installed for the particular purpose, and perhaps the major change has come about through the need for cold instead of hot working, but making use of the latter as a corrective measure if required.

The following review will be understood to refer to the cold working of materials to form them to the shape required, and apart from flame-cutting operations, the practices of the factory concerned are wholly on a cold worked basis.

A typical layout for welding shop on line production methods provides for detail preparation, sub-assembly, welding, final assembly, completion of welding, inspection and finishing, to shipment. There are, of course, intervening operations such as sand-blasting and testing for particular products. The general equipment is of necessity robust in character, and consists mainly of guillotine shearing machines, flame-cutting machines, notching and cropping machines, and cold saws. Plate edge-planing machines, plate and bar rolls, folding machines, and hydraulic presses, etc.

Flame-cutting machines are substantially a mechanisation of the hand torch, and as such are capable of producing shapes to comparatively fine limits. Oxy-gas or oxy-acetylene usually afford the cutting medium, the former giving a cleaner cut but not quite so speedy in action for pre-heating before commencement of cut. An oxy-gas cut is always amenable to subsequent treatment, but on occasion an oxy-acetylene cut may harden off and prove difficult of machining. The change in structure of the base material adjacent to the cut is not seriously affected and therefore, flame-cut parts in mild steel may be used without further preparation or treatment, but disturbances due to the general heating of the piece not infrequently occasion subsequent flattening or setting operation.

A clean flame-cut edge is not detrimental to good welding, although any form of oxide or scale may occasion impurities in the weld, and it may also be mentioned that a flame-cut edge lends itself to subsequent forming operations without starting a crack at the edges. A sheared edge on the other hand will not bend without cracking unless the burr is removed or else by bending the part with the burred edge on the inside. The rolling and forming of plate and sections are comparatively simple operations if not forced and correctly prepared.

The forming of heavy shells for motor frames and other circular

components is carried out on hydraulic presses, either by fixed or adjustable dies, the preparation being similar to that for rolling. The forming of small components, such as brackets, hangers, footsteps and the like, is dealt with on smaller presses, the tools being a flame-cut and welded product usually made from surplus materials. An advantage by forming small components on a hydraulic press, lies in the fact that variations of hardness can be accommodated by an extra squeeze—not advisable on a power press. The hydraulic method is of course much slower, but compensation for speed is accounted for by forming in multiple. As a guide for D. O. use, data relative to rolling and forming is tabulated in convenient form together with the capacity of the various machines. A set of these reference sheets are available for examination.

The assembly and welding of the prepared details assumes an infinite variety of methods, and calls for a specialised training particularly with regard to the assembly operations. The assemblers are of the mechanic class, and not trained as welders but have to be able to efficiently tack weld the parts together before handing over to the welders. The assembler is required to compensate for disturbances as previously referred to, which involves following a definite operation sequence, by no means easy of correct solution for each and every job.

Sub-assembly operations take an important part in any construction, and particularly those of large dimensions, because one is able to correct any deformations that may arise from welding, etc., before building the sub-assemblies into the main assemblies. The practice also affords the adoption of progressive inspection, and in consequence facilitates the inspection of the complete job. Inspection between operations of detail parts to check for dimensions, form and flatness is a very necessary service and aids considerably in obtaining a correct assembly, which could otherwise assume excesses due to the increment build up of a dimension by the use of nominal size sections when juxtaposed.

Machining allowances, on fabricated constructions with a view to saving material, and in other cases because the section does not permit of greater allowances, are very small as compared with that of castings. An average dimension on quite a large surface would be one-eighth of an inch and not infrequently one-sixteenth of an inch is generously given on both flat surfaces, also rings and shells. Even large baseplates of 30 ft. or over in length have an allowance of three-sixteenths of an inch each side for machining. It will be gathered, therefore, that progressive checking or inspection is a necessity for maintenance of dimensions.

As an aid to the inspection department for the finish of welds, the shops are provided with a board of standard welds to which an

operator is referred if his work falls much below the set standard. These standard welds can be readily lived up to by the average welder, and they are of very definite service in maintaining a weld of neat appearance. The inspection or testing of welds for oil tightness is an exacting process, and every oil-tight vessel, including some with a pressure test, have to show no signs of leakage at the end of 24 hours from the filling with hot oil at about 90° C. To check for leakages, all welds are whitened and any damp spot, however small, is recorded and has to be eliminated and test repeated before a tank will be passed for service. To give some idea of the leakages recorded over a period of several months, the average runs out at one leak per *100* feet of welding.

Various methods can be employed for the testing of welds, and may be divided into two classes—destructive and non-destructive. The destructive class usually applied to test pieces either as a welder's test or as a test piece, made at the same time as the weld of a job as an indication of its quality, are for tensile and ductability, the latter being effected by means of a bend test specimen bent around a bar equal in diameter to the thickness of test piece, or a fatigue test specimen subject to reversals of stress, either by rotation or by electro magnetic vibration in special machines. The results of weld tests specimens should be compared with similar tests taken on the parent metal to be of any value, and tests of deposited weld metal also afford valuable information.

The non-destructive class can be applied to actual welded jobs, the methods being—Stethoscopic, X-ray, Gamma Ray, and Magnetic. Of these the X and Gamma Ray are most likely to provide an accurate measure of the soundness of a weld, the latter, although of quite recent origin, appears to have a wide field of action as compared with the X-ray system. I have a few small prints which illustrate the character of the information given by the X-ray.

The stethoscopic and magnetic methods are no more reliable than a hammer test, which, together with an intuition borne by experience, is probably the present accepted method of testing welds for general fabrications. For pressure vessels the X-ray is the only means of ensuring that the whole of the welding therein is free of porosity and other defects. The process is expensive and is justifiable only on important constructions of a symmetrical character.

The progress we have reviewed, coupled with the activities of equal magnitude that are being conducted both in this country and abroad, by many industries, fares well for the future of fabrics tions in steel by means of the metallic arc. Official recognition of the process for assignable products will materially expedite the replacement of familiar riveted constructions, and in no less degree those now made of cast material. The change is but a

natural development of the joint efforts of science and industry time alone delaying its culmination.

In conclusion, the Author wishes to recognise the services that have afforded various data made use of in the paper, and to express his acknowledgments to the British Thomson-Houston Co. Ltd., for permission to publish the matter contained therein.

Discussion.

MR. J. D. SCAIFE (Section President, who presided) : Why is the term fabricated used instead of welded ? You mentioned high tensile steel. Will a welded joint of high tensile steel lend itself to heat treatment ? In the case of the welding of the edge of a piece of steel on to a flat plate, does this have to be chamfered, or is it possible to weld it true and get a solid weld ? The principles outlined in this paper can be applied with advantages in other constructions, for instance, in Machine Tool constructions, ribs in many cases, can be welded into large units more conveniently and with less expense than coring.

MR. HAWKINS : Fabrication is a term used to indicate the composition of a construction and can be applied to processes other than welding. The term " Weldings " is finding favour, and may ultimately be universally used to define a construction of welded steel in the same way as " Castings " is now understood to apply to founded products. In the case of high tensile steel, we are dealing with a totally different material to ordinary mild steel, and its weldability is mainly influenced by the carbon contact. It may be necessary to normalise both before and after welding, and if welding is satisfactory it should lend itself to heat treatment. It is not necessary to chamfer unless the weld interfered with some constructional feature. For good welding into a corner it is necessary to firstly use a small electrode to ensure proper penetration right into the corner. If a large electrode is used, metal may not be deposited right into the corner, whether chamfered or not, because the sides of the electrode being nearer to the plates than the apex of corner, would arc to the nearest points (i.e. sideways), and in consequence the corner would be bridged by a hollow fillet.

MR. GROOCOCK : The design must be suitable for the operation which welders have to perform, and design should be stressed. A designer can make a casting which will crack every time the Foundry take it out of the sand. The question of design should have particular attention at all times, but with welded constructions it is more important that design and constructive methods should work hand-in-hand.

MR. HAWKINS : Up to the present, sufficient heed has not been paid to design, probably because the problems connected with welding have been considered of a manufacturing order only, but if everybody associated with welding had to manoeuvre around the many problems in daily contact, they would soon fall in line with the need for a correct design for efficient welding.

MR. AIERS : Can you satisfactorily weld stainless steel ? With

the fabricated method against the castings, did you take into account the cost of material used in welding, also the cost of electricity and time, or did you just take labour charges? Would that vary with the size of the job? On a large job I can see it would be a big saving, but I cannot think this would be the case on smaller jobs. You mentioned that you use the same kind of material for the welding sticks, but in your next sentence you said it was rather different with wrought and cast material. You also mentioned some heat fatigue figures; I take it that the piece was heat treated. Is there any danger from explosion when using hydrogen? You have not dealt very largely with the plastic weld. I should have thought you would have got a better join with the plastic.

MR. HAWKINS: Yes. A sample of stainless steel welding is exhibited. The costs illustrated are inclusive of all overhead charges, but exclusive of the cost of patterns for the cast comparisons. The weight of the jobs illustrated varied from one hundred to 40 thousand pounds, and even suitable jobs of a few pounds in weight will show up to advantage by welding. With welding, the main thing is to get the weld metal of such a character that it will be as similar as possible to the base metal so that they will give equal service. The constituents of the rod for welding mild steel are generally similar to the latter, but for a good joint it is not necessarily so, because a brazed joint whilst possessing the same features physically is entirely different chemically. The reference to wrought and cast material, was to illustrate the nature of the process, i.e. the welding of wrought mild steel plates together is accomplished by the progressive laying down of the electrode, virtually in a cast form, and therefore, the science of the process is to cause the weld, originally deposited, cast in character to ultimately assume a character similar to that of the wrought base material. Analyses have shown that by the use of suitable rods and protection to the arc during welding, that a weld has similar characteristics to the base material. The reference to fatigue was for the purpose of indicating the requirements of a weld that in service would be subject to strain or shock, and in the case of mild steel weldings, it is not necessary to heat treat to obtain the required characteristics. Heat treating or normalising for the removal of locked up stresses, by heating up to not more than 500° C., is very desirable for certain structures, but opinion as to heat treating to rectify the structure of low carbon steels is divided. Hydrogen gas properly controlled is quite safe. Resistance welding can be applied to all simple sections, such as the joint of rings, frames, etc., but to apply it in a general way would prove costly, because of the special contacts and heavy currents required. By whatever means a given job is welded, approximately the same

energy is consumed. Resistance welding reduces the time element, and, therefore, the gain by this must exceed the cost of contacts, etc., to be economic.

MR. GRIFFITHS: The design of articles to be produced as fabricated structures means a new conception of design, wherein beauty must be sacrificed for utility, and even machine tools have not yet reached the stage of ugliness of jigs and fixtures, which are usually built on the ideal for a fabricated structure. The development is interesting, but I hope that in its present stage it will be limited.

MR. HAWKINS: The first requirement of most industrial designs is serviceability, and if we are to take full advantage of all that welding offers we may have to sacrifice so-called beauty of outline. Welding offers something better and cheaper, and unless the materials available are used to advantage the cost will be enhanced by a feature that really does not matter. The machine tool industry is rather slow to make use of welding in this country, but it will eventually be accepted, as may be instanced by the developments in Germany who have advanced in welded machine constructions to date, probably more than any other country.